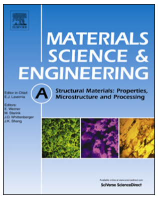
Materials Science & Engineering A 725 (2018) 98–107

Contents lists available at ScienceDirect

Materials Science & Engineering A

journal homepage: www.elsevier.com/locate/msea



Microstructural evolution and performance change of a carburized nanostructured bainitic bearing steel during rolling contact fatigue process

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ARTICLE INFO

Keywords:
Nanostructured bainite
Bearing steel
Rolling contact fatigue
Microstructure
Mechanical property
Fracture

ABSTRACT

The nanostructured bainitic (NB) bearing steel exhibits excellent rolling contact fatigue (RCF) resistance, which is critical to the service of bearing. However, the detailed microstructural evolution of the steel during the RCF process is still unclear. In this paper, a carburized NB bearing steel was studied and a detailed process investigation on microstructural evolution of the steel during the RCF progress was carried out. Results show that the nano-sized bainitic ferrite is gradually refined, and the undissolved carbide

s gradually flake away and some of them remain in solution during the RCF process. It is interesting to find that there are three stages for the martensitic transformation of retained austenite. During the first stage of 0–0.48 × 10^7 cycles, nearly all of the block-like retained austenite in the top surface transforms into martensite rapidly, and during the second stage of about 0.48–1.92 × 10^7 cycles, nearly no retained austenite further transforms into martensite, but when the fatigue exceeds the 1.92 × 10^7 cycles, the film-like retained austenite gradually transforms into martensite at a slow rate. The transformed martensite not only increases the surface hardness but further brings additional residual compressive stress in surface layer. It is analyzed from the microstructure characterization along the longitudinal section of the fatigue specimen that the fatigue crakes are initiated at subsurface of specimen, which propagate up to the surface and finally result in fatigue flake.

1. Introduction

Bearings are the basic and key mechanical components in the mechanical industry. The microstructure of the bearing directly determines its service life. The conventional microstructure of bearing steel is martensite with a small amount of retained austenite and carbide [1]. After a long time's investigation, lower bainite was also introduced in the manufacture of bearing. Recently, the newly developed nanostructured bainite (NB) attracts considerable attention because of its excellent properties of high strength and high toughness [2–5]. At 2008, Zhang et al. firstly developed a NB microstructure on the surface of a carburized steel via low temperature austempering treatment [6], which exhibited more excellent rolling contact fatigue (RCF) resistance as compared with martensite carburized steel [7]. This technique was thought to auger well for the development of case-hardening technology based on the NB [8]. Liu et al. also found that the NB microstructure effectively improved the RCF life of an ultrahigh carbon steel for its high toughness, and the L_{10} life of specimen with 21 ± 1 vol% nanobainite was approximately 3.3 times longer than that of specimen without nanobainite [9].

Due the promising properties and structure of NB, researchers realize that NB microstructure has a wide range of application on bearings. Peet et al. firstly studied the axial fatigue behavior of NB steel, and a fatigue limit of ~ 855 MPa was estimated assuming no failure in 10^7 cycles, based on extrapolation of data in which the maximum number of cycles permitted was 10^5 [10]. Solano-Alvarez et al. found that the damage mechanism of carbide-free NB steel was quite different from the conventional martensite bearing steel, which revealed that the ductile void formed at the interface of martensite and bainitic ferrite, followed by growth and coalescence into larger voids that caused fracture along the direction of the softer phase [11]. Moreover, the usefulness for the eventual usage of NB steel in rolling bearing was proved. Yang et al., analyzed that the newly developed NB bearing steel like G23Cr2Ni2Si1Mo and GCr15Si1Mo, presented a much higher RCF life than that of conventional G20Cr2Ni4 and GCr15SiMo steel, respectively [12]. Wang et al. revealed that the RCF life of the carburized NB steel was superior to that of the high-carbon NB steel, which is attributed to the finer carbide dispersed within the microstructure of the top surface and the higher residual compressive stress values in the carburized NB steel [13]. Moreover, the larger amount of retained

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https://doi.org/10.1016/j.msea.2018.04.015
Received 9 November 2017; Received in revised form 3 March 2018; Accepted 4 April 2018

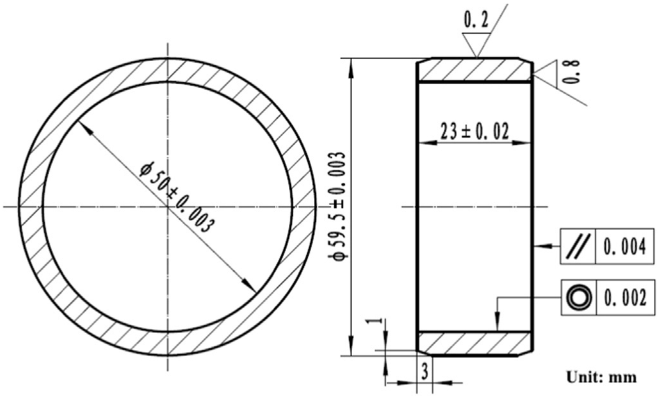

Fig. 1. Sketch of specimen for RCF test.

austenite played a key role for the excellent RCF performance of the carburized NB steel [13].

Huge research on NB steel proposed that NB steel possesses an excellent RCF resistance. However, the NB microstructure containing undissolved carbide during the RCF process has not been reported yet, which is important for revealing the fatigue mechanism of the NB bearing. A kind of newly developed carburized NB bearing steel, G23Cr2Ni2Si1Mo, was introduced and the progress research was carried out on the tested steel, with an aim of revealing the detailed evolution of each constitution phase during the RCF process. The variation of the hardness and residual stress were also studied to analyze the effect of the microstructural evolution.

2. Experimental methods

The chemical composition of the studied steel is Fe-0.23C-0.34Mn-1.43Si-2.30Ni-1.55Cr-0.30 Mo-0.043Al (wt%). The specimens were carburized in a controllable gas carburizing furnace and then were tempered at high-temperature of 650 °C for 3 h. After high-temperature tempering, the specimens were austenitized at 860 °C for 0.5 h followed by austempering treatment at 200 °C for 8 h in a salt bath. Finally, all specimens were tempered at 200 °C for 1 h. The carbon content at the top surface was determined to be ~ 0.80 wt% using a spectrometer model PAD-5500 II.

The sketch for dimension of specimens for RCF tests is shown in Fig. 1. RCF test was carried out at room temperature and on a TLP-2B model RCF testing machine. The rotating speed of the specimen was 1000 rpm and the testing load was 2500 MPa. The N32 mechanical oil was used as lubricant. The fatigue cycles of specimen were tested firstly, which was 6.02×10^7 cycles. And then, the other four un-failure specimens tested for different cycles (0.14×10^7, 0.48×10^7, 1.92×10^7, 2.86×10^7 and 5.15×10^7, respectively) were obtained.

Microstructures of the specimens before and after the RCF testing were examined using optical microscopy (OM, Axiovert 200MAT), scanning electron microscopy (SEM, SU-5000) and transmission electron microscopy (TEM, JEM-2010). The OM and SEM specimens were mechanically ground, chemically polished and etched with 3% Nital reagent. The TEM specimens were thinned to perforation on a TenuPol-5 twin-jet unit, at a voltage of 26 V with an electrolyte consisting of 7% perchloric acid and 93% glacial acetic acid. The amount of retained austenite content and the lattice of the phase were analyzed by a D/max-2500/PC X-ray diffractometer (XRD) with Cu Kα radiation. The scan rate is $2^\circ\,\text{min}^{-1}$.

The hardness distribution along the depth from the carburized

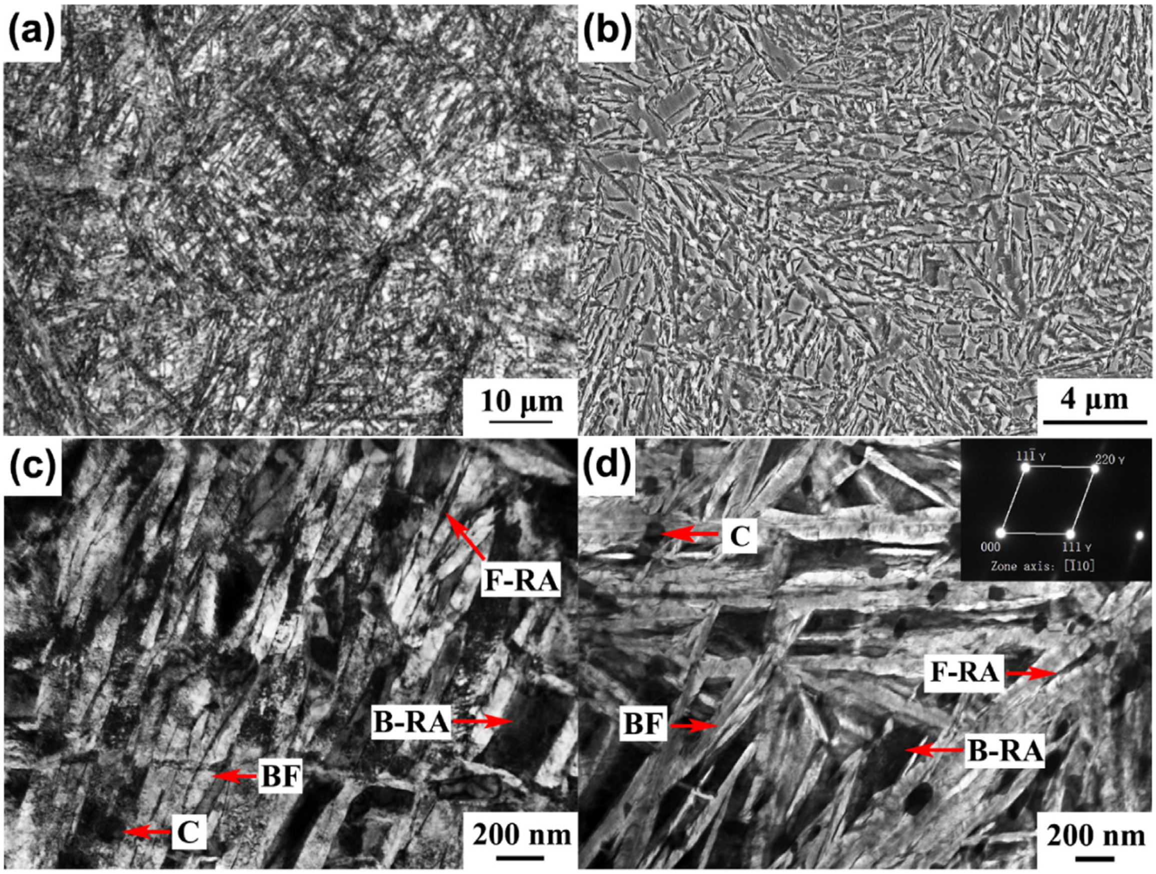

Fig. 2. Micrographs of the top surface of specimens before RCF testing: (a) optical micrograph, (b) SEM micrograph and (c, d) TEM micrographs. Notes: BF: bainitic ferrite, BA: block-like retained austenite, FA: film-like retained austenite, C: undissolved carbide.